Energy Prices and Capital Formation: 1972-1977

JOHN A. TATOM

TWO of the most noteworthy developments in the U.S. economy during this decade have been the sharp rise in energy prices in 1973-74 and the sluggish pace of business investment during the brisk economic expansion which followed the 1974-75 recession. The purpose of this article is to delineate the connection between these two developments. The analysis presented provides a perspective on the behavior of business investment spending in the recent past, and the general effects of energy price changes on investment and productivity.[1]

I. Investment and Energy Prices: The Theory

A standard view of the investment decision is that a profit-maximizing firm determines whether or not to invest in an asset by comparing the purchase price of the asset to the present value of the additional net receipts obtained over the life of the asset. The firm will invest whenever the purchase price of an asset is smaller than the present value of net receipts. At the margin, the present value of the net receipts attributed to the purchase and use of the asset will be equal to its purchase price or replacement cost.

A rise in the price of energy resources generally reduces the incentive for firms to use and, therefore, to invest in plant and equipment. The net receipts expected from the asset in future periods are reduced by an amount equal to the higher energy costs, other things remaining the same. This, however, ignores such factors as product prices, the price of capital goods, and other resource employment, which also affect the investment decision and can be expected to change when energy resources become more expensive. In order to take these factors into account, the relationship between the purchase price of a capital asset and the present value of net receipts can be rearranged to focus upon the production and capital employment decision.

Since the decision to invest implies that, at the margin, the price of the capital asset equals the present value of the expected net receipts, a "rental price" can be computed for any capital asset on the basis of this equality. This rental price is merely the cost *per period* of holding and using the capital asset and is directly proportional to the purchase price of capital goods[2]. The optimal amount of capital for a firm to employ can be determined using this price.

This article draws upon the author's paper "The New Energy Regime and Investment" (unpublished) which was prepared for a Federal Reserve Board of Governors study on Capital Formation. The author is grateful for the comments on the earlier paper by Nancy Ammon Jianakoplos, Patrick Lawler, and Robert H. Rasche.

[1]There are many factors which may have adversely affected business investment in plant and equipment in the recent past, such as safety and pollution regulations, inflation, large fiscal deficits, and increased uncertainty. The significant common feature of these developments is that they existed to some extent since the mid-sixties but, prior to 1974, did not seem to exert the profound influence required to explain recent developments. These other factors are ignored below.

[2]Generally, the rental price is the periodic cost of the equity and debt required to finance the replacement cost of the asset, the value of the asset lost per period due to depreciation, and taxes on the revenues from the use of the asset. Since it is proportional to the purchase price of a capital good, the terms are used interchangeably below.

An additional unit of capital used per period, holding other resource employment constant, generates additional output and revenue per period. The profitability of employing additional capital depends upon a comparison of the additional receipts and the price of the additional capital. The optimal employment of capital occurs when all profitable opportunities which yield greater net revenues than their associated costs have been exhausted. Thus, at the margin, the optimal employment of capital occurs when the value of the marginal product of capital goods equals the rental price of capital goods. Such a condition may be written as:

$$P_x f_K = P_K \tag{1}$$

where P_x is a given price of product x, f_K is the marginal product of capital goods (the additional output produced with the addition of a unit of capital, holding other resources fixed), and P_K is the rental price of capital. A similar relationship holds for the employment of every other resource used by an economically efficient firm.

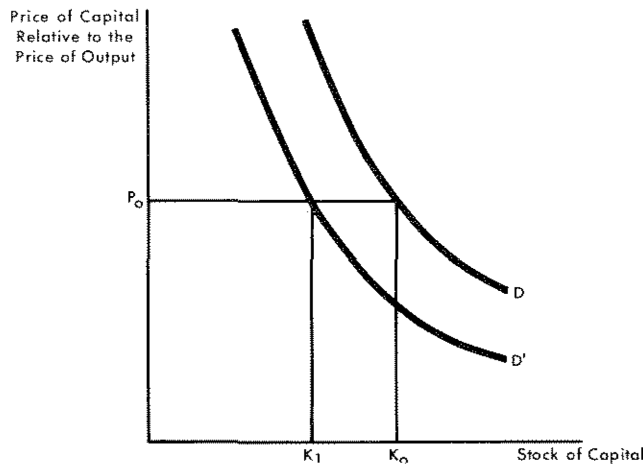
The principle of diminishing returns plays an important role in the determination of the optimal capital usage. The use of more plant and equipment leads to greater output, but successive additions of capital result in successively smaller additions to output, unless more of other resources are also employed. Thus, at some point, the additional output generates additional revenues sufficient to cover only the price of capital. In short, the value of the marginal product [designated P_xf_K in equation (1)] declines as employment of capital increases, other resources remaining the same.

An increase in the price of energy resources affects costs of production and prices throughout the economy. The unit cost of existing output and the cost of producing additional output tend to rise in proportion to the share of total cost attributable to energy resources. Moreover, firms reduce energy use as it becomes more expensive relative to output prices.

A reduction of energy use, in turn, reduces the marginal productivity of other resources. Employment of a non-energy resource will tend to decline unless its price relative to the output price (e.g., P_K/P_x for capital) falls proportionately with the decline in its marginal product, (e.g., f_K for capital). Should such a decline occur, there would be no change in the optimal employment of the resource, since equation (1) would hold at the employment rates which were optimal prior to the energy price boost.

Figure 1

The Effect of Higher Energy Prices on the Desired Stock of Capital



It is unlikely, however, that such a decline in the "real price" of capital (the price of capital relative to the price of output) would occur for the typical firm. If the share of energy costs in the production of capital goods is the same as the average cost share for all output, then the price of the nation's capital goods will rise in the same proportion as the prices of all other products. The real price of capital goods is essentially unchanged, while the marginal productivity of capital goods is lower. Thus, the desired employment of capital will fall. Investment slows temporarily to adjust the actual stock of capital to the lower desired amount.

If the production of capital goods uses relatively more energy than production of other goods, the price of capital goods rises even more than output prices. Since the rental price of such goods is directly proportional to the price of the goods, the real rental price of capital would rise, further reducing both the desired capital stock and investment.[3]

The failure of the relative cost of capital to decline provides an incentive for firms to reduce their desired stock of capital along with energy usage. The effect on the *aggregate* desired stock of capital may be seen in Figure 1, where initially the demand curve D indicates the aggregate demand for capital at alter-

[3]The analysis here can be used to find the inter-industry investment effects of higher energy prices. These are explored more fully in Tatom, "The New Energy Regime and Investment." Differential adjustments across industries can be expected primarily because the relationship of product prices to the prices of capital goods is affected differently across industries in response to an energy price increase.

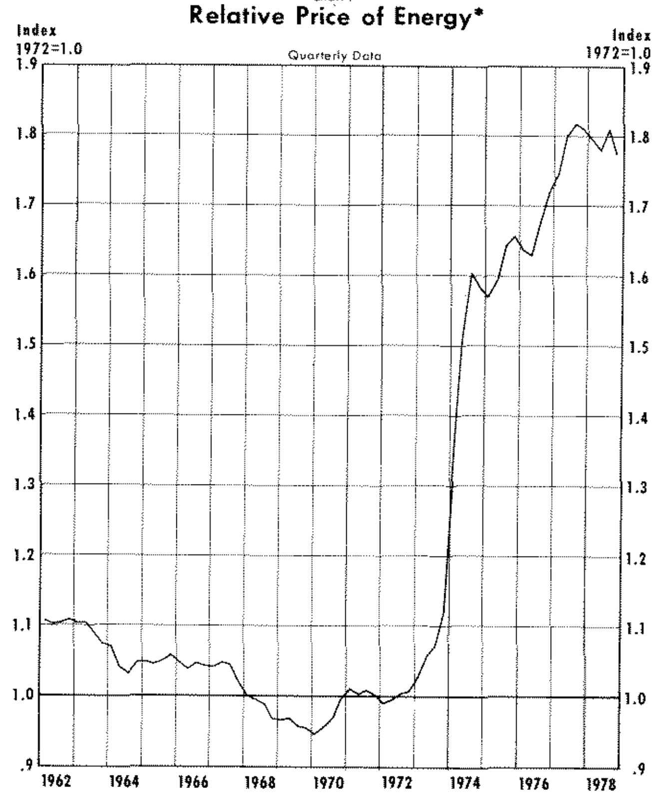
native prices of capital relative to the price of output, p_K. Factors which affect the desired stock of capital other than the relative cost of its services are held constant along D. Initially, the economy is assumed to be in equilibrium, given the relative price of capital p_0, holding the actual capital stock, K_0.

A rise in the relative price of energy shifts the demand for capital downward, as less energy is used to produce output with any given stock of capital and given flow of labor services.[4] In effect, the downward shift in demand to D′ indicates a decline in the marginal productivity of capital due to employment of less energy. If the real price of capital remains at p_0, however, the desired capital stock falls to K_1. In the aggregate, investment declines so as to reduce the capital stock from K_0 to K_1.

A rise in the relative price of energy will cause an initial reduction in output, induced primarily by a reduction in the use of energy resources. If the price of capital rises with the price of output, the desired capital stock is also reduced. Since capital is more expensive relative to its productivity, firms will also economize on its use, temporarily reducing investment.[5]

Chart I

Relative Price of Energy*



Sources: U.S. Department of Labor and U.S. Department of Commerce

*The Producer Price Index of Fuels, Power, and Related Products divided by the Implicit Price Deflator for the Private Business Sector.

Latest data plotted: 4th quarter

II. The Evidence

There are two basic implications of this theory. First, a rise in the price of energy relative to output leads to a decline in the productivity of *existing* capital and labor resources. Second, aggregate investment will slow temporarily, reflecting a decline in firms' desired capital use.

The first implication has been supported by an earlier study which showed that a rise in the relative price of energy reduces output, holding constant hours of employment and the flow of capital services.[6] The period studied is 1948-75, but similar results are reported for the period prior to the sharp rise in energy prices in 1973. A recent estimate of the quarterly production function (I/48-II/78) is:

$$(2) \qquad \ln\left(\frac{y}{k}\right) = \underset{(16.33)}{1.5492} + \underset{(21.69)}{.7135} \ln\left(\frac{h}{k}\right) - \underset{(-6.42)}{.1081} \ln\left(\frac{P_e}{P}\right) + \underset{(15.86)}{.0045}\, t$$

$R^2 = .98$ $\qquad$ D.W. = 1.92

S.E. = .007 $\qquad$ $\hat{\rho} = .79$

where y is real output in the private business sector, k is a measure of the flow of capital services [the product of the Federal Reserve Board capacity utilization rate and the net stock of private nonresiden-

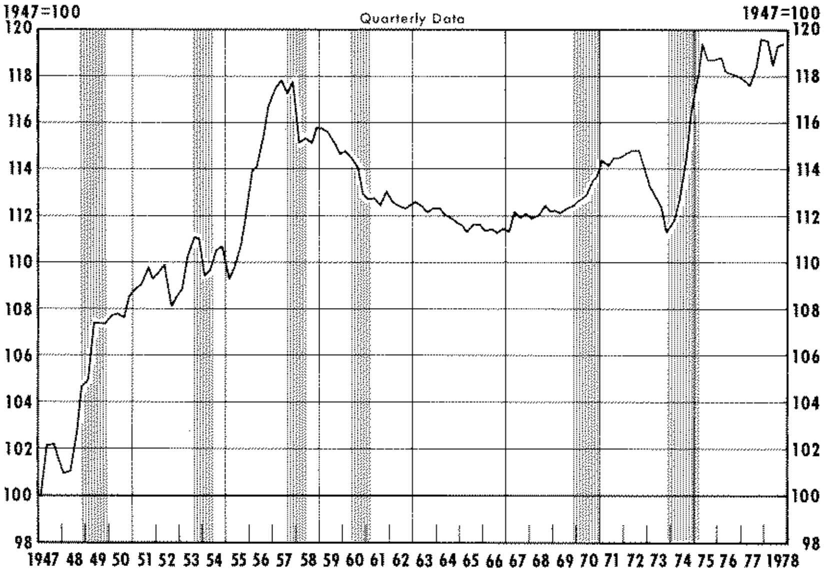
[4]At K_0 along D′, the relative price of labor is sufficiently lower for the quantity of labor to be the same as along D. This assumes that the supply of labor to the economy is fixed and that the shift downward in the marginal product of labor is reflected in a decline in the real wage. Whether the supply of labor is affected by an energy-induced fall in the real wage is unclear. So-called income and substitution effects of a real wage decline may lead to reductions in labor supply, while an associated decline in the real value of monetary and physical wealth tends to increase labor supply. The net effect is assumed to be zero here. Leonall C. Andersen, "An Explanation of Movements in the Labor Force Participation Rate, 1957-76," this *Review* (August 1978), pp. 7-21, provides evidence that the permanent net effect arising from the 1974 experience is zero.

[5]The results explained in this section may be derived using a simple aggregate model of output supply and factor employment. See the Appendix at the end of this article.

[6]See Robert H. Rasche and John A. Tatom, "Energy Resources and Potential GNP," this *Review* (June 1977), pp. 10-24, and "Potential Output and Its Growth Rate — The Dominance of Higher Energy Costs in the 1970's," in *U.S. Production Capacity: Estimating the Utilization Gap* (St. Louis: Center for the Study of American Business, Washington University, Working Paper 23, December 1977), pp. 67-106.

Chart II

Relative Price of Capital Goods*



Sources: U.S. Department of Commerce and U.S. Department of Labor

Shaded areas represent periods of business recessions.

Note: First quarter 1947=100

*Ratio of the Implicit Price Deflator of Nonresidential Fixed Investment to the Implicit Price Deflator for the Private Business Sector.

Latest data plotted: 4th quarter

tial fixed capital], h is manhours in the private business sector, $(\frac{P_e}{P})$ is the producer price index for fuel, related products, and power deflated by the private business sector price deflator, and t is a time trend. The numbers in parentheses are t-statistics.

The significant negative impact of the relative price of energy on output per unit of capital indicates the existence and extent of a productivity loss associated with a rise in the relative price of energy. Chart I shows that, from the second quarter of 1972 through the end of 1977, the relative price of energy rose 60 percent (all percentages are measured as first differences in logarithms). The direct loss in productivity (measured relative to labor or capital) is 6.5 percent ($60 \times .1081$) according to the production function above. Two-thirds of this loss occurred during the year from the third quarter of 1973 to the third quarter of 1974, when the relative price of energy rose 40 percent.

The second major implication of the analysis is that the aggregate desired stock of capital declined due to the sharp rise in the price of energy relative to the price of output, and that the recent sluggish pace of business investment is due, in large part, to this decline. This result rests upon the assumption that the price of capital goods relative to output prices did not fall subsequent to the energy price increase.

In Chart II, the price of new capital goods relative to the price of output is shown for the period 1947-78. It is clear from the chart that the relative price of capital goods did not decline subsequent to the sharp rise in the relative price of energy in 1973-74. Instead, it increased until early 1975, and has been fairly stable since. The rise in the real replacement cost of capital during 1973-74 may have occurred because the production of capital goods is relatively more energy intensive than the production of private output generally. In this case, the price of capital goods would rise more than the average level of output prices when energy costs rise. The increase in the real replacement cost of capital goods further reduces the incentive to invest.

Chart III shows quarterly estimates of the net stock of fixed nonresidential capital from 1948-78.[7] The trend rate of growth of the stock of plant and equipment from 1948 to the first quarter of 1975 is 4.1 percent. As the chart indicates, the rate of growth slowed markedly during 1975-77. From I/75 to IV/77, the annual rate of growth averaged only 2.3 percent. Some slowdown in the rate of capital accumulation might be expected due to the prior recession and accompanying lower levels of capacity utilization and employment from III/74-I/75. A visual comparison of earlier recoveries following the shaded recession periods in Chart III indicates that the recent slowing is unusual compared to prior early expansion periods.

[7]The estimates are constructed by interpolating the end of year net stock prepared by the U.S. Department of Commerce for the period 1948-75. The interpolation uses quarterly rates of constant dollar nonresidential fixed investment in the GNP accounts as weights in finding end-of-quarter net capital stocks. After 1975, the estimates are based upon the prior (II/48-IV/75) relationship of the rate of nonresidential fixed investment (I_t) and the lagged net capital stock, to account for depreciation. The equation (t-statistics in parentheses) is:

$$\Delta K_t = 1.012 + .2457\, I_t - .0252\, K_{t-1}$$
$$(4.5) \quad (29.2) \quad (-21.4)$$

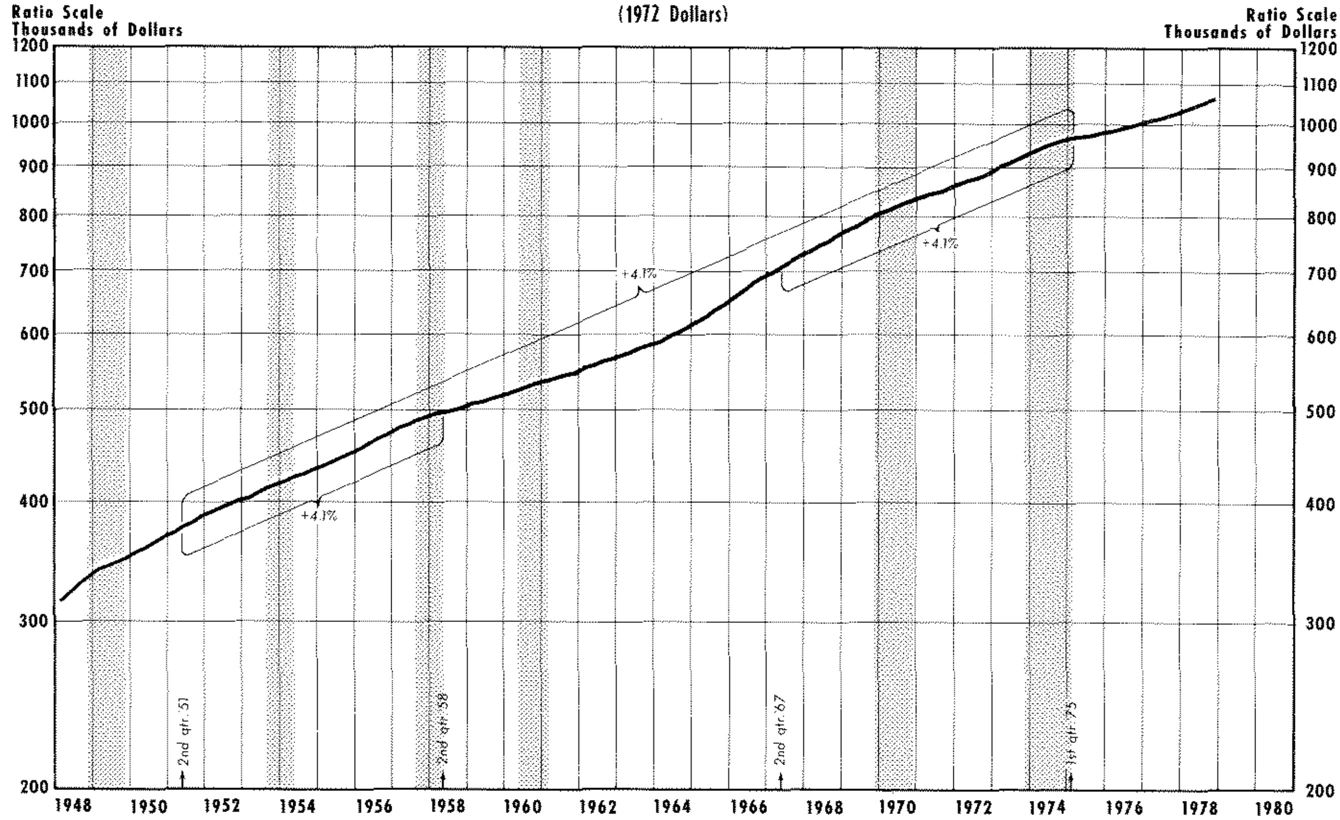
$R^2 = .98$ D.W. $= 2.10$

S.E. $= .37$ $\hat{\rho} = .49$

Chart III

Net Capital Stock

(1972 Dollars)



Shaded areas represent periods of business recessions.
Percentages are annual rates of change for periods indicated.
Latest data plotted: 4th quarter 1978

Basic data source: U.S. Department of Commerce

The slowing in capital investment is even more apparent when viewed relative to the growth of potential private sector employment. Chart IV shows the historical growth pattern of the capital stock relative to the high employment supply of workers. The capital stock in any quarter is measured by the existing stock at the end of the prior quarter. Potential private business sector employment is measured by adjusting the actual labor force, less employment outside the private sector, for the full-employment unemployment rate.[8] In effect, the employment measures are estimated under full employment conditions. Until the third quarter of 1973, the ratio of available capital to available labor grew at an annual trend rate of 2.9 percent. From the third quarter of 1973 until the end of the recession, the growth rate slowed. During the ensuing expansion, the ratio of capital stock to potential employment remained virtually unchanged.

Chart III and IV provide illustrations of the slowdown in capital accumulation implied by the theory above, and support the claim that this energy-induced slowdown in capital growth caused a temporary reduction in the growth rate of potential output after 1973.[9] Two questions obviously arise, however. First, how large is the energy-induced reduction in the capital-labor ratio, and to what extent has it already occurred? Second, how large are the energy-induced output and capital stock reductions along a high-employment growth path, when the effects of higher energy prices are aggregated? The output effects are (1) the short-run loss in productivity, given capital

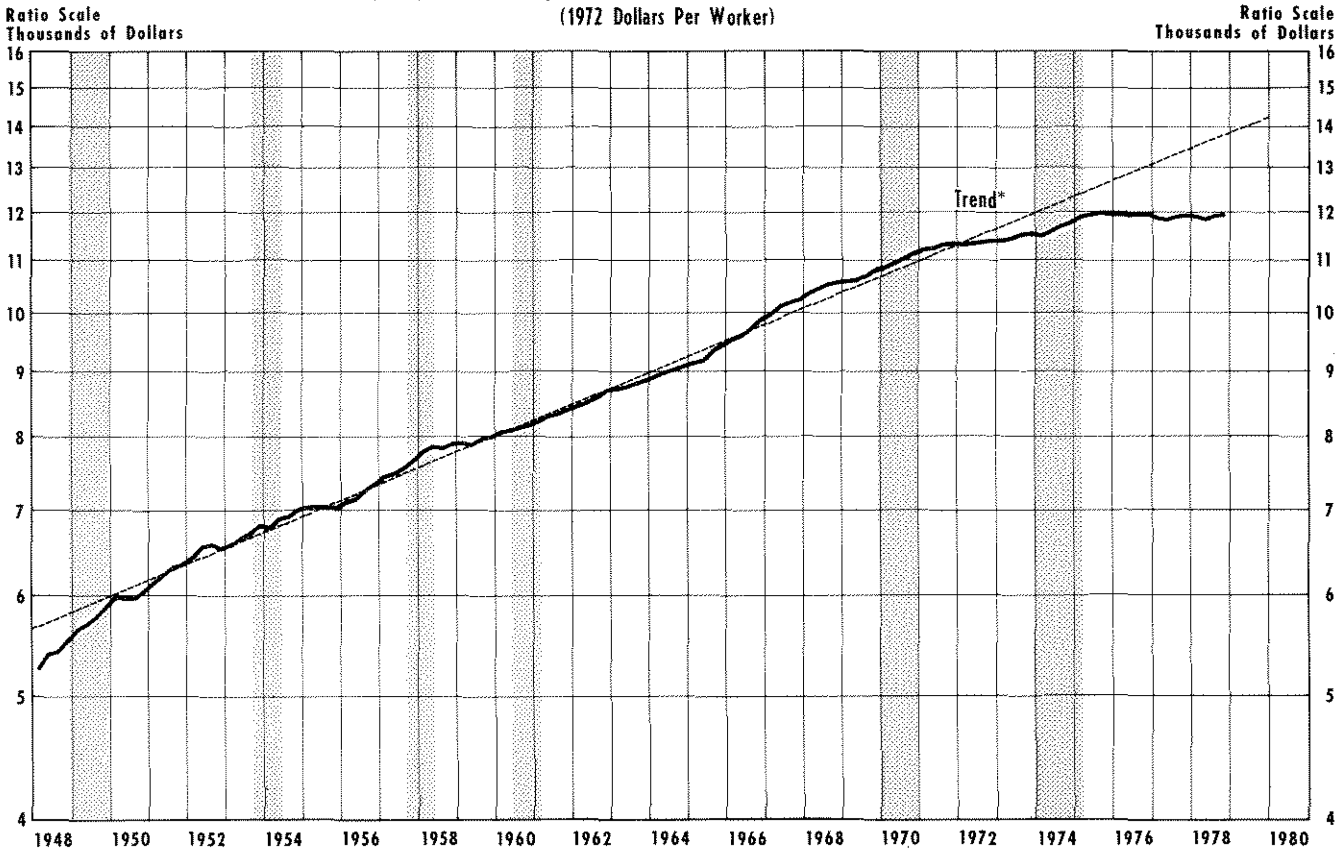
[8]The full-employment unemployment rate series used is that developed by Peter K. Clark, "Potential GNP in the United States, 1948-80," in *U.S. Productive Capacity: Estimating the Utilization Gap* (St. Louis: Washington University, Center for the Study of American Business, 1977), pp. 21-66. The series is constructed to find an unemployment rate comparable to four percent in 1955, after adjustment for changes in the age and sex composition of the labor force.

[9]See Rasche and Tatom, "Potential Output and Its Growth Rate." The estimate of the potential growth rate is three percent from early 1975 through mid-1977. This slowing should not be confused with the once-and-for-all decline in productivity, given capital and labor, implied by the theory and evident in 1974 productivity developments.

Chart IV

Full-Employment Capital-Labor Ratio in the Private Sector

(1972 Dollars Per Worker)



*An annual trend rate of growth (2.9%) is estimated by a regression of the logarithm of the capital-labor ratio on time for the period I/1950—II/1972.

Shaded areas represent periods of business recessions.

Latest data plotted: 4th quarter 1978

Basic data sources: U.S. Department of Commerce and U.S. Department of Labor

and labor employment in the United States, and (2) the loss in output due to the long-run adjustment to the energy-induced decline in the capital-labor ratio.[10]

These questions may be answered using the estimate of the production function given in equation (2). The percentage change in output for a one percent rise in the relative price of energy in the long run is $(-\frac{\gamma}{\alpha})$, where α and γ are the output elasticities of labor and energy employment, respectively.[11] Estimates of α and γ, found from the estimated equation (2), with standard errors are:

$$\text{(3)} \qquad \hat{\alpha} = .6439\ (.0271)$$
$$\hat{\gamma} = .0976\ (.0137)$$

The short-run capacity loss for each one percent increase in the relative price of energy is found from the coefficient on the energy price in equation (2), which is an estimate of $(\frac{-\gamma}{1-\gamma})$, or in this case, –.1081. The total response $(-\frac{\gamma}{\alpha})$ measures the long-run effect when capital employment adjusts to its long-run equilibrium, given an unchanged real price of capital. The estimates in (3) indicate that the long-run output effect is 40.2 percent larger (–.1516) than the short-run effect. For the rise in the cost of energy from mid-1972 through 1977, the short-run output

[10]A third effect, due to an energy-induced rise in the relative price of capital, has not been well substantiated by detailed econometric analysis and so it is not incorporated in the estimates in the text. To the extent such an effect exists, the estimates below are too low.

[11]The production function is $y = Ae^{rt} h^{\alpha} k^{\beta} E^{\gamma}$, where E is energy and α, β, γ, the output elasticities of the respective inputs which seem to unity. See Rasche and Tatom, "Energy Resources and Potential GNP." The derivation of the expression used here follows from mathematical conditions required for efficient long-run employment of capital and energy, given the aggregate supply of labor and the real rental price of capital. This expression and other mathematical results below are derived in the Appendix.

loss is 6.5 percent while the long-run response allowing capital to adjust is 9.1 percent.[12]

The total effect on the demand for capital may be found from the condition for profit-maximizing capital demand, $p_k = \beta\frac{y}{k}$, where β is the output elasticity of capital and p_k is the price of capital relative to the price of output. Given p_k and the parameter β, the ultimate percentage decline in the desired capital stock must equal the percentage decline in output in order to maintain the equality. The elasticity measure for the total output response above is −.1516. Thus, the 60 percent rise in the relative price of energy from mid-1972 through 1977 would reduce the capital-labor ratio by 9.1 percent along its new long-run growth path.[13] The decline in the actual capital-labor ratio relative to its past trend is 12 percent, when the trend is extrapolated from mid-1972 through the end of 1977, consistent with the reduction indicated by energy price considerations alone.

The results indicate the costs associated with the rise in the relative price of energy from 1972-1977. In terms of output, the cost of the adjustment by the end of 1977 was a 9.1 percent reduction, much of which occurred during the period from III/73 to III/74. Most of the loss was due to the direct effect on productivity of a higher relative cost of energy and changes in resource allocation, given domestic capital and labor resources. An estimated 2.6 percentage points of the loss in output occurred subsequently, due to the energy price-induced slowing in capital formation. The net capital stock at the end of 1977 in the estimates above is $1,031.8 billion (1972 prices), while the estimates imply it would have been $98.3 billion larger in the absence of the dramatic change in energy costs over the preceding five years.[14]

III. The Remaining Adjustment and Recent Developments

Energy prices in world markets have not fully adjusted to past OPEC actions because of U.S. energy policy. Decontrol of the U.S. petroleum market will complete the adjustment and will further affect future production.

Since 1973, the primary component of energy policy has been the entitlement program. This program was intended to hold the cost of petroleum to U.S. refiners below the OPEC price to allow for a longer transition period to the higher prices. The average cost of crude oil to refiners at the end of 1977 was about 18 percent below the cost of imported oil.[15] An earlier analysis indicates that, based on this difference, the end of the entitlements program would add about 7.8 percent to the relative price of energy resources.[16] This increase results from a direct effect on the price of refined products, cost effects on competing energy producers, and substitution effects among energy uses. Given the estimates of the short-run and long-run impacts of higher energy costs above, it is possible to assess the output loss in the short and long run due to this change. In the short run, the output loss is less than 1 percent. Even allowing for the effects on the demand for capital, the total long-run effect is a loss in output and capital stock of 1.2 percent.

This loss should be regarded as a maximum estimate, had the crude oil market been completely decontrolled at the end of 1977. The reason is that such a policy would increase the responsiveness of world (U.S.) petroleum supplies to the world price, increasing the elasticity of demand faced by the dominant firm, the OPEC cartel, and putting downward pressure on their optimal price. Thus, the effect of

---

[12]If the price of capital goods relative to output prices is affected by the rise in energy prices, then another element must be added to the long-run output loss $(-\frac{\beta \ d\ln P_k}{\alpha \ d\ln P_e})$, where β is the output elasticity of capital. One simple estimate of the price responsiveness, for quarterly data from 1948-77, is .0564 when the logarithm of the relative price of capital is related to the logarithm of the relative price of energy and constant, and the equation is estimated using the Cochrane-Orcutt technique. The addition to the output elasticity $(-\frac{\gamma}{\alpha} = -.1516)$ is 2.27 percent. Thus, a 60 percent in energy prices would add only about 1.4 percent to the output loss over the long run.

[13]Accounting for the energy price effect on the relative price of capital would add .0791 to the capital elasticity (in absolute value), implying a 13.8 percent reduction in the capital stock.

[14]This estimate is very close to that by Edward A. Hudson and Dale W. Jorgenson, "Energy Prices and the U.S. Economy," *Natural Resources Journal* (October 1978), pp. 877-97, and *Data Resources U.S. Review* (September 1978), pp. I.24-I.37. They estimate that by the end of 1976, the U.S. capital stock was $103 billion (1972 prices) lower than it otherwise would have been due to energy price developments.

[15]This is the percentage excess of the refiner acquisition cost of imported crude oil over the composite cost in late 1977 reported by the Department of Energy, *Monthly Energy Review* (August 1978), pp. 58.

[16]See Rasche and Tatom, "Potential Output and Its Growth Rate," pp. 93-97.

decontrol on production and investment would have been slight in the United States.

During 1978, there was little change in the relative price of energy. Although the pace of capital accumulation increased during the year — the net stock of capital grew 3.5 percent from the end of 1977 to the end of 1978 — the capital-labor ratio was virtually unchanged. During the year, the gap between the U.S. average cost of crude oil and the world price narrowed, averaging about 12 percent by the end of 1978. Thus, the implied impact of domestic petroleum market decontrol was reduced sharply.[17]

Political developments in the Middle East late in 1978 and early in 1979 led to a sharp disruption in petroleum supplies and subsequently changed the structure of OPEC supply. Coincident with these developments, OPEC announced an increase in the cartel price of crude oil by about 14 percent during 1979. OPEC later adjusted to supply developments by hastening the announced increase and by allowing individual countries to impose additional surcharges on production. The result has been another round of boosts in petroleum prices in the world market and, indirectly, the prices of other sources of energy.

It is tenuous to speculate on the final outcome of recent developments on the price of OPEC crude oil and the impact on U.S. energy costs. However, nominal energy prices have risen at a 31 percent annual rate from November 1978 to May 1979. Based upon an 8.5 percent rate of increase of the implicit price deflator for private business sector output from the fourth quarter of 1978 to the first quarter of 1979, the relative price of energy has been rising at about a 22 percent annual rate. During the six-month period from November to May, the relative price of energy increased about 11 percent, implying a short-run productivity loss and price level rise, according to the estimates above, of 1.2 percentage points. The implied long-run productivity and capital stock reduction is 1.7 percent.[18]

IV. Conclusion

The large increase in the cost of energy resources from 1972 to 1977 has had profound effects on productivity, investment, and the long-term growth path of the U.S. economy. In addition to a direct loss in productivity of about 6.5 percent, a reduction in the desired capital-labor ratio has further aggravated productivity growth. Since 1975, growth in the capital stock has barely kept pace with growth in the labor force available to the private sector. This development represents a significant departure from the trend growth in the capital-labor ratio, a trend which contributed significantly to overall economic growth in the United States prior to 1973.

The analysis and estimates here indicate that a drop of at least 9 percent in the desired capital-labor ratio is to be expected from the sharp rise in the relative cost of energy which occurred from mid-1972 through 1977. This represents about three years growth in capital relative to labor on the pre-1974 trend. Once such an adjustment is completed, there is no reason to presume that other forces contributing to capital formation will be offset by the effects of past energy price changes. Unfortunately, recent events in the world petroleum market suggest that another round of lesser adjustments of resource allocation, capital formation, and economic growth will occur before such forces again dominate the scene.

---

[17]The estimate of this difference is based upon an imputed cost of imports and U.S. average cost of all crude oil found by adding the price of an entitlement to the wellhead price of lower tier oil, plus twenty-one cents, to find the average world price. The domestic cost is found by subtracting the entitlement benefit from import cost. The calculation uses quarterly averages of monthly figures. The comparable figure for the fourth quarter of 1977 is 16 percent. Data on the refiner acquisition cost of imported oil during the fourth quarter of 1978 is not available at the time of this calculation. The data and definitions of terms are from the *Monthly Energy Review* (April 1979). A more detailed discussion of these terms and the analysis of the entitlement program may be found in John A. Tatom, "Energy Policy and Prices," *Business Economics*, (January 1979), pp. 14-22.

[18]Of course, these increases do not fully reflect OPEC actions as existing policy insulates U.S. energy prices from OPEC actions. Thus, recent energy price increases in the United States (and their effects) are only about half as large as they would have been otherwise. The remainder of the increase will be phased in over the next eighteen months under the administration's decontrol proposal. It would be erroneous to conclude that these developments increase the cost to U.S. consumers of a decontrol program, since decontrol yields positive *net* benefits to U.S. consumers. The adverse impacts associated with such a program are indeed larger, but the *net* benefit to consumers of decontrol is correspondingly larger. See Tatom, "Energy Policy and Prices."

APPENDIX

Higher Energy Costs: The Long Run and the Short

The results discussed in this paper may be demonstrated using a simple model of aggregate production. Consider a general aggregate production function with the assumption of profit-maximization and the most general assumptions for short- and long-run resource constraints. Assume that aggregate output, y, depends upon the use of labor (h), capital (k), and energy (e), $y = f(h, k, e)$, given technology. The short run is characterized by fixed supplies of labor and capital resources (h^o, k^o) and by a given relative price of energy resources, p_e^o, determined in the world market. In the long run, the supply of capital is variable as firms can add to or subtract from the stock of capital depending on their incentives. The relative price of capital (measured relative to the price of output) is assumed to be given in the long run. The long-run supply of labor and relative price of energy are assumed to be the same as in the short run (h^o, p_e^o).

The profit-maximizing choice of an input is determined by equating the marginal cost (price) of the resource to the value of its marginal product, $f_i = p_i$, where f_i is the marginal productivity of resource i ($\frac{\partial y}{\partial i}$) and p_i is the rental price of the resource relative to the price of aggregate output. The production function, profit-maximizing demand for each of the three inputs, and the three supply equations which hold in the short run or the long run can be used to determine output and employment of each resource as well as their relative prices. The short-run and long-run models are shown in Table I. By differentiating each system of equations, the short-run and long-run response to a rise in the relative price of energy may be found to be those indicated in Table II.

Table I

A Simple Model of Aggregate Supply and Resource Markets

Production Function:	$y = f(h, k, e)$
First-Order Conditions For Profit-Maximization:	$p_h = f_h$
	$p_k = f_k$
	$p_e = f_e$
Short-run Resource Supply Assumptions:	$h = h^o$
	$k = k^o$
	$p_e = p_e^o$
Long-run Resource Supply Assumptions:	$h = h^o$
	$p_k = p_k^o$
	$p_e = p_e^o$

Definitions:
- y = output
- h = labor
- k = capital
- e = energy
- p_h = wage of labor relative to the price of output
- p_k = rental price of capital relative to the price of output
- p_e = price of energy relative to the price of output

The critical unknown determinant of the effects shown in Table II is the sign of f_{ij} for $i, j = k, h, e$. This term indicates the effect of an increase in the employment of factor j on the marginal productivity of a resource i. The typical response is positive; employment of more of one resource is generally responsible for increased marginal productivity of the other resources.[1] The generality of the results in Table II indicates the importance of the sign of f_{ij}. The signs of f_{ee}, f_{kk}, f_{hh} are assumed to be negative, indicating diminishing returns to the employment of each resource.

The short-run output effect discussed in the text rests upon the assumptions of a positive marginal product of energy and diminishing returns to the employment of energy resources, given capital and labor. The effect arises solely due to the reduction of energy employment, given the assumptions concerning the supply of labor and capital. Under the assumption that energy resources augment the marginal productivity of capital and labor, the real rental price of capital and labor must fall to maintain their em-

[1]The term f_{ij} is positive in the three factor Cobb-Douglas production function where the resources are substitutes, or $\sigma_{ij} > 0$. The term f_{ij} is also positive if $\sigma_{ij} < 0$, or the resources are complements. The determinant of the negative capital stock effect can be referred to as "q-complementarity" which must be the case if $\sigma_{ij} < 0$ and will be the case for Cobb-Douglas and CES production functions where $\sigma_{ij} > 0$, or resources are "p-substitutes." On this terminology and these relationships, see John R. Hicks, "Elasticity of Substitution Again: Substitutes and Complements," *Oxford Economic Papers*, 22, no. 3 (November 1970), pp. 289-296, and Ryuzo Sato and Tetsunori Koizumi, "On The Elasticities of Substitution and Complementarity," *Oxford Economic Papers*, 22, no. 1 (March 1973), pp. 44-59. Whether capital and energy are substitutes or complements (in the "p" sense) is a continuing controversy. See Ernst R. Berndt and David O. Wood, "Engineering and Econometric Interpretations of Energy-Capital Complementarity," *American Economic Review*, (June 1979), pp. 342-354. Fortunately, the issue does not affect the capital stock-investment result, but it is important for such questions as short-run output supply effects and changes in the amount of energy used per unit of capital.

Table II

The Effect of a Rise in the Relative Price of Energy

		Short Run	Long Run*
Output:	$\frac{dy}{dp_e} =$	$\frac{f_e}{f_{ee}} < 0$	$\frac{-(f_e f_{kk} - f_k f_{ke})}{\lvert D\rvert} < 0^{**}$
Labor Employment:	$\frac{dh}{dp_e} =$	0	0
Capital Employment:	$\frac{dk}{dp_e} =$	0	$\frac{f_{ke}}{\lvert D\rvert} < 0^{**}$
Energy Employment:	$\frac{de}{dp_e} =$	$\frac{1}{f_{ee}} < 0$	$\frac{-f_{kk}}{\lvert D\rvert} < 0$
Relative Price of Labor:	$\frac{dp_h}{dp_e} =$	$\frac{f_{he}}{f_{ee}} < 0^{**}$	$\frac{(f_{hk} f_{ke} - f_{kk} f_{he})}{\lvert D\rvert} < 0^{**}$
Relative Price of Capital Services:	$\frac{dp_k}{dp_e} =$	$\frac{f_{ke}}{f_{ee}} < 0^{**}$	0

*$|D| = -(f_{kk} f_{ee} - f_{ke}^2) < 0$.

**Sign depends upon f_{ke} and/or $f_{he} > 0$.

ployment. If energy employment has no effect on the productivity of capital and labor, no shift in demand for capital and labor occurs. If increases in energy employment reduced the marginal productivity of labor or capital, the demand price of the factor would rise.

The long-run effects of a rise in the relative price of energy are also unambiguous, given that $f_{ke} > 0$. Not only are output and energy usage reduced as in the short run, the employment of capital is also reduced. Of course, this result arises from a temporary reduction in investment to achieve the smaller amount of capital desired. The results show that the economy will reduce the use of capital goods since they have become more expensive in relation to the productivity of such goods. Subtracting the long-run output effect from the short-run effect results in:

$$(1) \qquad \frac{f_{ke}\,(f_e f_{ke} - f_k f_{ee})}{f_{ee}\,|D|}$$

which is positive, given that f_{ke} is positive (f_{ee}, $|D| < 0$). Thus, the long-run output effect of the rise in the relative cost of energy is larger than the short-run effect. Similar computations indicate that the long-run reduction in energy usage and the decline in the real wage rate of labor are also larger than in the short run. The increased size of the long-run effects arises from the reduction of capital employment through a temporary reduction in investment.

For the particular case of a Cobb-Douglas production function, the model is even simpler. The production function is $y = A\, h^{\alpha} k^{\beta} e^{\gamma}$, where α, β, γ are the respective output elasticities of the inputs: labor, capital, and energy and they sum to one. The term A is a scale factor; a rate of neutral technological change (r) over time (t) is omitted here for simplicity and to avoid notational confusion. The first order conditions are: $p_e = \frac{\gamma y}{e}$, $p_h = \frac{\alpha y}{h}$, and $p_k = \frac{\beta y}{k}$. For the analysis in the text, it is most convenient to compute the effects in Table II in elasticity form. Since labor and the relative price of energy are fixed in the short and long run, the production function can conveniently be rewritten as:

$$(2) \ \ln y = \ln A^* + \frac{\alpha}{1-\gamma} \ln h + \frac{\beta}{1-\gamma} \ln k - \frac{\gamma}{1-\gamma} \ln p_e$$

by substituting the first-order condition for energy employment in the production function. Then, given labor and capital employment, the short-run effect of a rise in the relative price of energy is $\frac{d \ln y}{d \ln p_e} = -\frac{\gamma}{1-\gamma}$.

The first-order condition for capital employment requires: $\ln k = \ln \beta + \ln y - \ln p_k$. In the short-run ($d \ln k = 0$), a decline in output is reflected in an equal percentage decline in the real value of capital, p_k. The long-run results require $d \ln p_k = 0$, so $d \ln k = d \ln y$. Substituting the expression for ln k in (2) and differentiating with respect to $\ln p_e$ results in $\frac{d \ln y}{d \ln p_e} = \frac{d \ln k}{d \ln p_e} = -\frac{\gamma}{\alpha}$, given p_k and h. The implied long-run decline in the real wage ($\frac{d \ln p_h}{d \ln p_e}$) is also ($-\frac{\gamma}{\alpha}$), given labor employment and the real price of capital.